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Sustainable rubber production through good latex harvesting practices: stimulation based on clonal latex functional typology and tapping panel management

R. Lacote[1], A. Doumbia[2], S. Obouayeba[3], E. Gohet[4]

1. CIRAD, UPR Tree Crop-Based Systems, HRPP, R&D Building 3rd floor, Kasetsart University, Chatuchak, 10900 Bangkok, Thailand
2. EXAT, 18 BP 2508 Abidjan 18, Côte d'Ivoire
3. CNRA, 01 BP 1536 Abidjan 01, Côte d'Ivoire
4. CIRAD, UPR, Tree Crop-Based Systems, TA B/34, Montpellier F-34000, France

Corresponding author: Régis Lacote
Tel: +66 843267235, Fax: +66 29427628
regis.lacote@cirad.fr

ABSTRACT

The purpose of this study was to characterize the long-term behaviour of the rubber tree under different ethephon stimulation treatments and under different panel management strategies. Over a period of seven years in Côte d'Ivoire, the effect of a gradient of ethephon stimulation frequencies on yield and latex cell biochemistry was compared in four rubber tree clones, IRCA130, IRCA230, GT1 and PB217. The ability of the trees to produce more latex under ethephon stimulation was related to the sucrose and inorganic phosphorus contents of the latex cells. For high-yielding clones with low sugar content and high inorganic phosphorus content like IRCA130, no stimulation was necessary to improve yield. Conversely, the effect of ethephon stimulation on latex yield increase was significant in clones with high sucrose content and low inorganic phosphorus content such as PB217. Clones IRCA230 and GT1 had an intermediary behaviour, explained by a median sucrose content. These results will help planters to optimize latex production by choosing the most adapted ethephon stimulation to clones according to their latex cells biochemistry and their position in a clonal functional typology. A comparison of two tapping panel management strategies of rubber plots was also performed, differing by the number of panel changes: 1 and 7 panel's changes over a total period of 9 years. These treatments were applied to the clones PB260, GT1 and PB217. The panel management strongly influenced annual yield in each of the clones tested. No panel changing appeared detrimental to immediate latex production after 6 consecutive years of tapping on panel BO-1. However, after 9 years, the cumulated rubber yield obtained with one panel change only was as high as that of treatments with more changes.

Keywords: *Hevea brasiliensis*, ethephon stimulation, panel management, latex harvesting, latex cell biochemistry.

1 Introduction

In the new area of rubber extension, gradually shifting to marginal areas, two major issues for rubber production were identified by IRRDB as kilogram per hectare and tapper productivity. This matter of concern is addressing to land productivity and labour productivity. Skill farmers will be involved to face the challenges as sustainable practices to consider high yielding clones, well-tailored tapping systems to clones and the use of diverse technics of stimulation. The main issue is to focus on the reduction of the cost of production for the farmers and providing them a better income from their rubber fields.

Latex is extracted using a multi-annual tapping system that can continue for 15 to 30 years. Both small-scale planters and agro-industrial plantations worldwide use an ethylene generator, 2-chloroethylphosphonic acid (ethephon), applied to the tapping panel, which increases latex yield while reducing tapping frequency to increase land or labour productivity (Eschbach and Banchi, 1985; Sivakumaran and Chong, 1994; Lukman, 1995; Thanh *et al.*, 1996 and 1998; Vijayakumar *et al.*, 2000 and 2001). Gohet *et al.* (1995) reported that the ethephon stimulation effect may vary with rubber tree clones. Some former studies showed that the ethylene released by ethephon increases the duration of latex flow after tapping by activating latex cell metabolism (Lustinec and Resing, 1965; Pakianathan *et al.*, 1976; Jacob *et al,* 1989; d'Auzac *et al.*, 1997). Nowadays, yield stimulation offers opportunities to reduce the tapping frequency and to increase land or labour productivity (Sivakumaran et al., 1983, Sivakumaran and Chong, 1984, Eschbach and Banchi, 1985, Gohet et al., 1991, Lukman 1995, Gohet, 1996, Thanh, 1996 and 1998, Vijayakumar et al., 2000 and 2001). In this context, to improve the economic competitiveness through enhancing the tapping productivity, new high yielding clones are more often selected.

The clones tapping system technology has been backed by in-depth research devoted to the physiology of the laticifer tissue; this led to the development of the concept of yield potential of clones linked to the clonal metabolic typology (Commère et al, 1991, Gohet et al 1995, Gohet 1996). According to the clonal typology of functioning (Serres et al., 1988, Jacob et al., 1989, Gohet et al., 1995 and 1996), when opened for tapping, some clones favour the latex regeneration pathway but trough out the competition with the tree growth. In order to perform accurate clonal selection and tapping system recommendations there is a need to increase the knowledge of the relationships between latex synthesis, growth and yield to estimate then sustain the rubber potential yield in plantations.

The purpose of the first study was to compare the effect of the ethephon stimulation in two high-yield clones, IRCA130 and IRCA230, namely quick starter clones, with the GT1 (medium starter) and PB217 (slow starter) clones currently used in Côte d'Ivoire. We analysed both the relationship between latex yield obtained after different ethephon stimulation frequencies over a seven-year tapping period and the parameters involved in rubber biosynthesis, sucrose and inorganic phosphorus contents of the latex cells. For each clone, optimum ethephon stimulation was defined as the number of stimulations per year that produced the highest yield without causing physiological disturbances in the latex cells. The results will help managers choose clones according to the policy of each plantation and also optimize latex production through appropriate ethephon stimulation.

The purpose of the second study was to compare two panel management strategies differing by the number of panel changes over nine years. In Côte d'Ivoire, farmers use a half-spiral downward system (S/2) with a frequency of two tappings every week (d3 6d/7), or three tappings every two weeks (d4 6d/7). A minimum of ten years of downward tapping is possibly followed by a quarter-spiral (S/4) upward system (Gohet *et al.* 1991). Panel changing is generally considered useful for reducing the physiological stress generated in a panel by tapping (Eschbach *et al.* 1986). Panel changing after the first two tapping years has been generalized on clones in Côte d'Ivoire. These treatments were applied to three clones: PB260, GT1, and PB217 over a nine-year period. The objective is to determine the impact of these strategies on the cumulated yield after different periods, on the growth of the trees, and on laticifer physiology.

Today, there is still a need of research related to rubber tree crop physiology, crop production and management, in order to optimize the long-term yield of the clones by adjusting the latex harvesting technology to the physiology of the tree and by choosing the best-adapted clones to the local conditions of production. Given that rubber tree is a perennial crop, such research entails a considerable work for data measurements and data processing over several years.

2. Materials and methods

2.1. Plant material

In the first study, the four clones GT1, IRCA130, IRCA230 and PB217 belong to different classes, according to geneticists and agronomists. The trials were conducted during seven years, since 1998 until 2005, at the Hevego Rubber Research Station in southwest Côte d'Ivoire.
In the second study, Clones PB260, GT1 and PB217, were studied in four experiments in the Cnra research station of Bimbresso in southeast Côte d'Ivoire.
As the GT1 rubber clone is the most widely planted clone in Côte d'Ivoire, we used it as the control clone. According to Gohet *et al.* (2003), GT1 has medium inorganic phosphorus content and medium sucrose content, and a good yield response to ethephon stimulation; PB217, which has medium inorganic phosphorus and high sucrose contents, can be activated by intensive stimulation and has a very good yield response. Serres *et al.* (1988) and Gohet *et al.* (2003) reported that the other two clones, IRCA130 and IRCA230, differed from GT1 and PB217. IRCA130 and PB260 have a rapid

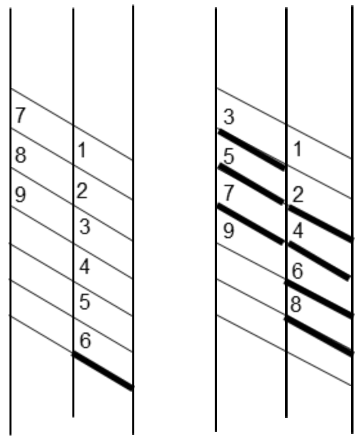
metabolism, with low sucrose content but high inorganic phosphorus content, IRCA230 also has a rapid metabolism and high inorganic phosphorus content, but its sucrose content is medium instead of low.

2.2. Experimental design

For each clone, the experimental plot was 3 ha. Trees were spaced at 7 m × 2.8 m (510 trees ha^{-1}. The experimental design was a "one-tree plot design" with 33 trees per treatment and total randomization of all the trees in a plot. Age of rubber trees of each clone, at the time of the beginning of the trial was 5 years old. The trees of equal and median girth were selected before starting tapping in order to avoid any initial bias due to girth difference

In the first study, during the seven-year experimental period, four rubber tree clones GT1, PB217, IRCA130, and IRCA230 were compared under eight annual frequencies of ethephon stimulation (eight treatments). We applied one gram of a mixture of palm oil containing ethephon with 2.5% active ingredient on the tapping cut per tree and per stimulation. The eight frequencies of ethephon stimulation applied to each clone were as follows: 0 (control), 2, 4, 8, 13, 26, 39, and 78 applications of ethephon per year. The tapping cut was located 1.20 m from the ground, at the standard trunk girth of 50 cm measured 1 m from the ground. Every four days, the trees were tapped with a half spiral downward cut, six days a week (S/2 d4 6d/7).

In the second study, trees were opened at the standard girth of the trunk (50 cm) at 1 m high. All the trees were opened at 1.20 m from the ground. The tapping system was S/2 d3 6d/7 12m/12 ET 2.5 % Pa 1(1).The two treatments presented hereafter (Figure 1) were 1 and 4 panel changes over the first six years and 1 and 7 panel changes over a total period of nine years respectively.



Treatment	A	B
Number of panel changes	One panel change after year 6	Seven panel changes after years 2, 3, 4, 5, 6, 7, and 8
At year 3	0	1
At year 6	0	4
At year 9	1	7

Figure 1. The four panel management systems.
Numbers of panel changes are indicated according to each period of tapping as follows: years 1–3, 4–6 and 7–9.
A : No panel change (1PC) on Panel BO-1 *and* BO-2 *opened in year 7 at 1.40 m;*
B : Annual panel change after two years on BO-1 *(control),* i.e. *seven panel changes (7PC) after 2, 3, 4, 5, 6, 7 and 8 years.*

2.4. Measurements and data processing

The latex yield per tree was measured by weighing the cumulative coagulated rubber from each tree every four weeks. Total solid content was measured from a bulk sample taken in each treatment in order to convert fresh weights into grams of dry rubber per tree. In the first study, latex yield was expressed in grams per tree per tapping and per centimetre of cut length (g/tree/tapping cm^{-1}) to avoid any effect of the girth on yield. The average latex yield obtained without stimulation was denoted by P0 and the highest average latex yield obtained with stimulation was denoted by Pmax.
As a result of the effect of stimulation frequency on yield, a difference (∆) was calculated for each clone, ∆P = Pmax – P0 which represented the gain in latex yield, in other word, the potential yield of the clone under stimulation.

The main latex biochemical parameters, i.e. sucrose and inorganic phosphorus contents, were measured tree by tree each year between September and November using methods developed by CIRAD and CNRA (Jacob *et al.*, 1988 and 1995) adapted in 1995 by IRRDB (1995). Sucrose and inorganic phosphorus contents were expressed in millimoles per litre of latex (mmol l^{-1}). The sucrose content measured for P0 was denoted by SUC_{P0}, and SUC_{Pmax} for Pmax. The inorganic phosphorus content measured for P0 was denoted by Pi_{P0}, and Pi_{Pmax} for Pmax. For each biochemical parameter, a ∆ was calculated: $\Delta SUC = SUC_{P0} - SUC_{Pmax}$, which represents sucrose consumption, ΔPi, = $Pi_{Pmax} - Pi_{P0,}$ which represents the increase in inorganic phosphorus.
A one way ANOVA was done per clone to compare the treatments of ethephon stimulation as it is known there is interaction between clone and number of ethephon stimulation (Gohet 1996, Gohet *et al*., 1996). All differences were tested for statistical significance using the Student-Newman-Keuls test with an alpha threshold of 0.05. Statistical analyses of latex yield and biochemical parameters were performed using Statbox 6.5 statistical software (Grimmer Soft).

3. Results

3.1. Long term effect of ethephon stimulation on the yield of rubber trees linked to latex cell biochemistry

3.1.1. Preliminary result: clone characterization without stimulation

Two groups of clones were identified (Table 1): one with lower yields, GT1 (control) and PB217; and one with higher yields, IRCA130 and IRCA230. PB217 had the highest sucrose content (SUC_{P0}) and the lowest inorganic phosphorus content (Pi_{P0}). IRCA130 had the lowest sucrose content (SUC_{P0}) and the highest inorganic phosphorus content (Pi_{P0}). High yields were associated with high latex inorganic phosphorus content (Pi_{P0}) and low sucrose content (SUC_{P0}).

Table 1: Average latex yield (P0), latex sucrose content (SUC_{P0}), and latex inorganic phosphorus content (Pi_{P0}) over seven years of tapping without stimulation in four rubber tree clones.

Clone	P0 (g/tree/tapping cm^{-1})	SUC_{P0} (mmol l^{-1})	Pi_{P0} (mmol l^{-1})
GT1	1.01 b	16.0 b	14.9 b
PB217	1.00 b	21.1 a	12.9 b
IRCA130	1.70 a	7.9 c	24.9 a
IRCA230	1.46 a	15.3 b	23.2 a

According to ANOVA, different letters in the column indicate a significant difference between clones at $P < 0.05$.

Correlations were observed between latex yield without stimulation (P0) and the clonal biochemical parameters of the latex whatever the clones (Fig. 1 and Fig. 2). P0 was positively correlated with the inorganic phosphorus content of the latex (Pi_{P0}); r = 0,979 (Fig. 1).

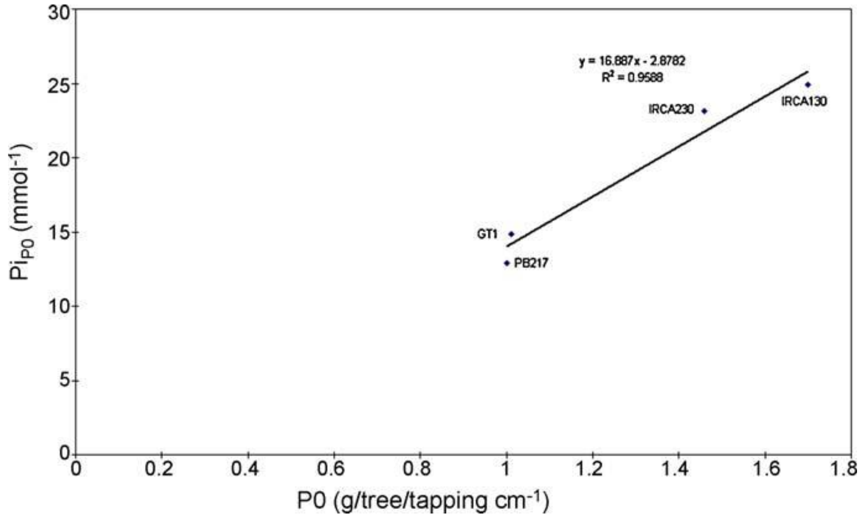


Fig. 1: Relationship between the inorganic phosphorus content measured for P0 (PiP0) and the latex yield obtained without stimulation (P0) in the four clones over a tapping period of 7 years (df between groups = 3, Pearson correlation, r = 0.979, P < 0.05).

Conversely, there was a tendency towards a negative but non-significant correlation (r = -0.869) between latex sucrose content (SUC_{P0}) and P0 (Fig. 2).

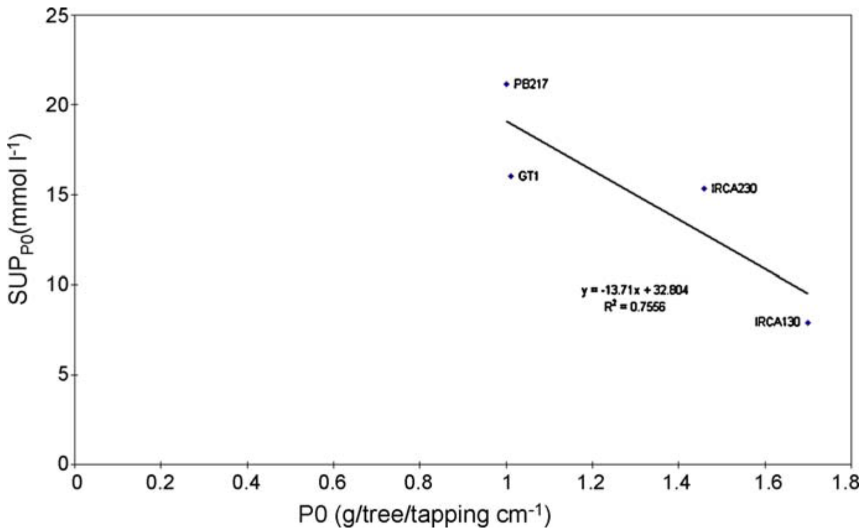


Fig 2: Relationship between the sucrose content measured for P0 (SucP0) and the latex yield obtained without stimulation (P0), in the four clones over a tapping period of 7 years (df between groups = 3, Pearson correlation, r = - 0.869, P < 0.05).

3.1.2. Effects of ethephon stimulation

In each clone a different optimum number of stimulations produced the highest latex yield, Pmax (Table 2). Clone PB217 was the most responsive to ethephon stimulation, with a gradual positive effect up to 39 applications per year. Clone IRCA130 was the only one to achieve the highest yield without any stimulation. Clones GT1 (control) and IRCA230 displayed intermediate responses to ethephon stimulation, with Pmax of respectively four and eight stimulations per year. The difference between the highest latex yield with stimulation and the latex yield without stimulation, ∆P (Pmax – P0), varied with the clone: the highest ∆P was obtained in clone PB217; ∆P equalled zero in IRCA130; GT1 and IRCA230 had an intermediate ∆P.

Table 2: Average latex yield (g/tree/tapping cm^{-1}) after seven years of tapping as affected by the annual ethephon stimulation frequency with ethephon in four rubber tree clones.

Number of stimulations per year	GT1	PB217	IRCA130	IRCA230
0	1.01 d ^{2}	1.00 e ^{2}	**1.70** ^{1}	1.46 de ^{1}
2	1.37 bc ^{2}	1.13 e ^{3}	1.58 ^{2}	1.76 bc ^{1}
4	**1.52** a ^{2}	1.29 d ^{3}	1.65 ^{2}	1.85 ab ^{1}
8	1.50 a $^{2\,3}$	1.44 c ^{3}	1.57 ^{2}	**1.91** a ^{1}
13	1.45 ab ^{3}	1.63 b $^{1\,2}$	1.55 $^{2\,3}$	1.73 cd ^{1}
18	1.49 a ^{3}	1.67 ab $^{1\,2}$	1.51 $^{2\,3}$	1.76 bc ^{1}
26	1.49 a ^{2}	1.73 ab ^{1}	1.53 ^{2}	1.69 cd ^{1}
39	1.44 ab ^{2}	**1.78** a ^{1}	1.53 ^{2}	1.51 e ^{2}
78	1.26 c ^{3}	1.67 ab ^{1}	1.52 $^{1\,2}$	1.47 e ^{2}
ΔP (Pmax-P0)	0.51	0.78	0.00	0.45

In bold: highest yield (Pmax) obtained with the optimum number of stimulations. According to ANOVA, different letters in the column indicate a significant difference in the frequency of ethephon stimulation at $P< 0.05$. Different numbers in the rows indicate a significant difference among clones for each stimulation frequency at $P< 0.05$.

Clones IRCA130 and IRCA230 displayed significantly higher Pi content than the control clone GT1 and clone PB217, whatever the stimulation frequency (Table 3). In clone IRCA130, which had the highest Pi_{P0}, consecutive ethephon stimulations did not induce significant differences in Pi until 78 ethephon stimulations per year. The main increase in Pi was obtained in clone PB217 which had the lowest $Pi_{P0.}$ The increase in inorganic phosphorus ($\Delta Pi = Pi_{Pmax} – Pi_{P0}$) was the highest in clone PB217, the increase was intermediate in the control clones GT1 and IRCA230, and zero in IRCA130.

Table 3: Average latex inorganic phosphorus content Pi (mmol l^{-1}) after seven years of tapping as affected by the frequency of ethephon stimulation in the year in four rubber tree clones.

Number of stimulations per year	GT1	PB217	IRCA130	IRCA230
0	14.9 b ^{2}	12.9 e ^{2}	**24.9** ^{1}	23.2 ab ^{1}
2	17.0 ab ^{2}	14.3 de ^{2}	25.4 ^{1}	22.4 b^{1}
4	**17.2** ab^{2}	15.7 cd ^{2}	26.9 ^{1}	22.9 ab ^{1}
8	18.0 a ^{2}	17.4 bc ^{2}	24.3 ^{1}	**24.9** ab ^{1}
13	17.1 ab ^{2}	17.7 b ^{2}	23.7 ^{1}	23.5 ab ^{1}
18	17.9 a ^{3}	20.1 a ^{2}	25.3 ^{1}	25.4 a ^{1}
26	16.8 ab ^{3}	21.2 a ^{2}	23.7 $^{1\,2}$	24.6 ab^{1}
39	17.3 a ^{3}	**20.1** a ^{2}	24.0 ^{1}	25.0 ab ^{1}
78	17.7 a ^{3}	19.9 a ^{3}	23.0 ^{2}	25.3 ab ^{1}
ΔPi (Pi_{Pma}-Pi_{P0})	2.3	7.2	0.0	1.7

In bold: latex inorganic phosphorus content for the highest yield (Pi_{Pmax}). According to ANOVA, different letters in the column indicate a significant difference in ethephon stimulation frequency at $P< 0.05$. Different numbers in the rows indicate a significant difference among clones for each stimulation frequency at $P< 0.05$.

Consecutive stimulations had a significantly detrimental effect on sucrose content in the control clone GT1, and in clones IRCA230 and PB217 (Table 4). This effect was significant up to a number of stimulations that varied with the clone: four in GT1, eight in IRCA230, and 13 in PB217. The effect of ethephon stimulation was not as clear in clone IRCA130 which had the lowest SUC_{P0} of the four clones and the lowest SUC for any stimulation frequency. PB217, showed the highest sucrose consumption ($\Delta SUC = SUC_{P0} – SUC_{Pmax}$) was the highest of the trial. In all four clones, there was a significant positive (r = 0.999) correlation between SUC_{P0} and ΔP, the higher the sucrose content prior to stimulation, the higher the yield increase after stimulation (Fig. 3).

Table 4: Average latex sucrose content SUC (mmol l^{-1}) after seven years of tapping as affected by the frequency of ethephon stimulation with ethephon in the year in four rubber tree clones.

Number of stimulations per year	GT1	PB217	IRCA130	IRCA230
0	16.0 a [2]	21.1 a [1]	**7.9** ab [3]	15.3 a [2]
2	14.6 ab [2]	17.1 b [1]	7.2 bc [2]	13.1 b [2]
4	**13.4** bc [1]	14.9 c [1]	8.5 a [2]	13.2 b [1]
8	13.8 b [1]	12.8 d [1]	6.9 c [1]	**10.8** c [1]
13	11.8 cd [1]	9.8 e [1 2]	7.4 bc [2]	9.8 c [1 2]
18	10.2 d [1]	8.9 e [2]	7.9 ab [2]	10.8 c [1]
26	10.4 d [1]	9.6 e [1]	8.1 ab [2]	10.8 c [1]
39	10.6 d [1]	**10.1** e [1]	8.2 ab [1]	10.0 c [1]
78	10.9 d [1]	9.0 e [1 2]	8.1 ab [2]	10.6 c [1]
ΔSUC (SUC_{P0}-SUC_{Pmax})	2.6	11.0	0.0	4.5

In bold: latex sucrose content with the highest yield (SUC_{Pmax}). According to ANOVA, different letters in the column indicate a significant difference in Ethephon stimulation at *P*< 0.05. Different numbers in the rows indicate a significant difference among clones for each stimulation frequency at *P*< 0.05.

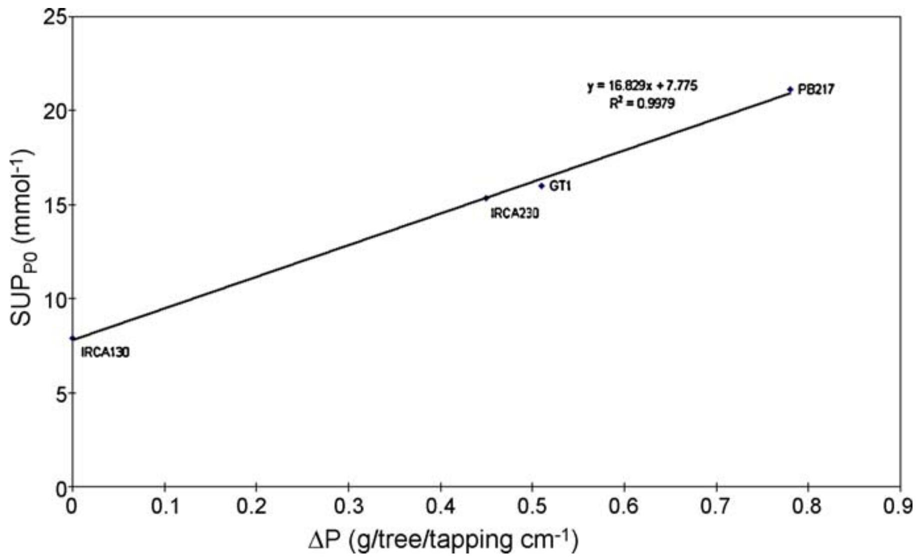


Fig. 3: Relationship between the sucrose content measured for the latex yield obtained without stimulation (SucP0) and the gain in latex yield DP (Pmax ———————————— P0) in the four clones over a tapping period of 7 years with the optimum number of ethephon stimulations for each clone (df between groups = 3, Pearson correlation, r = 0.999, P < 0.05).

Figure 4 shows different numbers of stimulations producing the highest latex yield the effect of consecutive stimulations on clones. Only PB217 showed a progressive effect of stimulation. IRCA130 showed a detrimental effect of more than 2 stimulations. Clones IRCA130 and IRCA230 displayed significantly higher Pi content than the control clone GT1 and clone PB217, whatever the stimulation frequency. Stimulation had the same effect on Pi than on yield for clone PB217 from a maximum at 39 stimulations per year. Consecutive stimulations had a significantly detrimental effect on sucrose content in the control clone GT1, and in clones IRCA230 and PB217. The effect of ethephon stimulation was not as clear in clone IRCA130 which had the lowest SUC for any stimulation frequency. Stimulation had a slight effect on RSH content for clone PB217 which showed the highest content whatever the stimulation frequency. Clones GT1 then IRCA230 and clone IRCA130 showed lower RSH content than clone PB217. For these clones stimulation had a detrimental effect on RSH content.

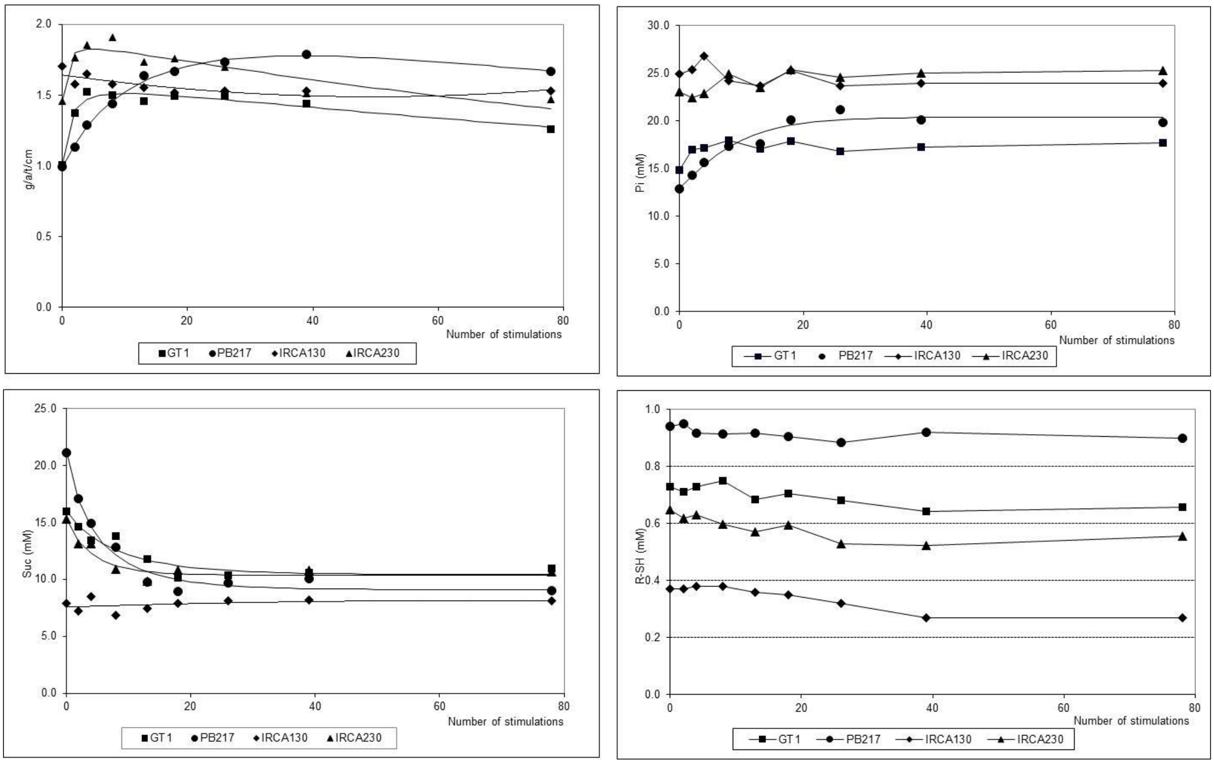


Fig.4: Effect of stimulation frequency on yield and the physiological parameters of the latex.

3.2. Panel management in rubber tapping (Hevea brasiliensis) and impact on yield and latex diagnosis

3.2.1. Effects of panel management on yield

Table 5 shows the cumulated latex yields of the four clones after 3, 6, and 9 years (Cy3, Cy6, and Cy9). The average Cy9 (over the four treatments) of PB260 was higher than that of GT1 and PB217 (+ 16 %).

After 3-year tapping period, Cy3, yield of treatment A was lower than yield of treatment B with 1 panel changing, for clones PB260 and GT1 (respectively –7% and –9%). Treatment A was equivalent to treatment B for clone PB217. After a 6-year tapping period, Cy6 of treatment A, still with no panel changing, was lower than yield of treatment B, with four panel changing, for clones PB260, GT1 and clone PB217. The yield increase of treatment B over treatment A was of 34 % for PB260, of 23 % for GT1, and of only 13 % for PB217. After a 9-year tapping period, treatment A was equivalent to treatment B with clones PB260, PB217 But for clone GT1, treatment A was higher producer than treatment B (+17%).

Table 5. Cumulative yield (kg/tree) after three, six, and nine years of tapping according to tapping panel-changing frequency for each clone. Statistical comparisons by Student-Newman-Keuls test, with alpha threshold of 0.05 (letters indicate significant levels of differences)

		A (1PC) One panel change after year 6	B (7PC) Ann. panel change after year 2
PB260	Cy3: Year 1 to 3	12,9 b	13,9 a
	Cy6: Year 1 to 6	25,4 b	34,0 a
	Cy9: Year 1 to 9	52,8	53,0
GT1	Cy3: Year 1 to 3	9,7 b	10,6 a
	Cy6: Year 1 to 6	23,4 b	28,7 a
	Cy9: Year 1 to 9	49,1 a	41,9 b
PB217	Cy3: Year 1 to 3	9,3	9,1
	Cy6: Year 1 to 6	22,2 b	25 a
	Cy9: Year 1 to 9	44,4	45,0
Average	Cy3: Year 1 to 3	10,6	11,2
	Cy6: Year 1 to 6	23.7 b	29,2 a
	Cy9: Year 7 to 9	48,8	46,6

Figure 5 shows the evolution of the yields per tree per year from year 1 to year 9. For PB260, the curves clearly show a low yield of treatment A in the second tapping period (years 5 to 6) on panel BO-1, and a high yield in the third tapping period (years 7 to 9) on panel BO-2. The same can be seen for GT1. This trend was not so clear but still existing for PB217. Considering treatment B, for both clones yield was more regular along the years of tapping than treatment A. But, a drop in yield was observed during years 7, 8 and 9, particularly important for GT1 while tapping the bottom of the panel BO-1 and the lower panel BO-2.

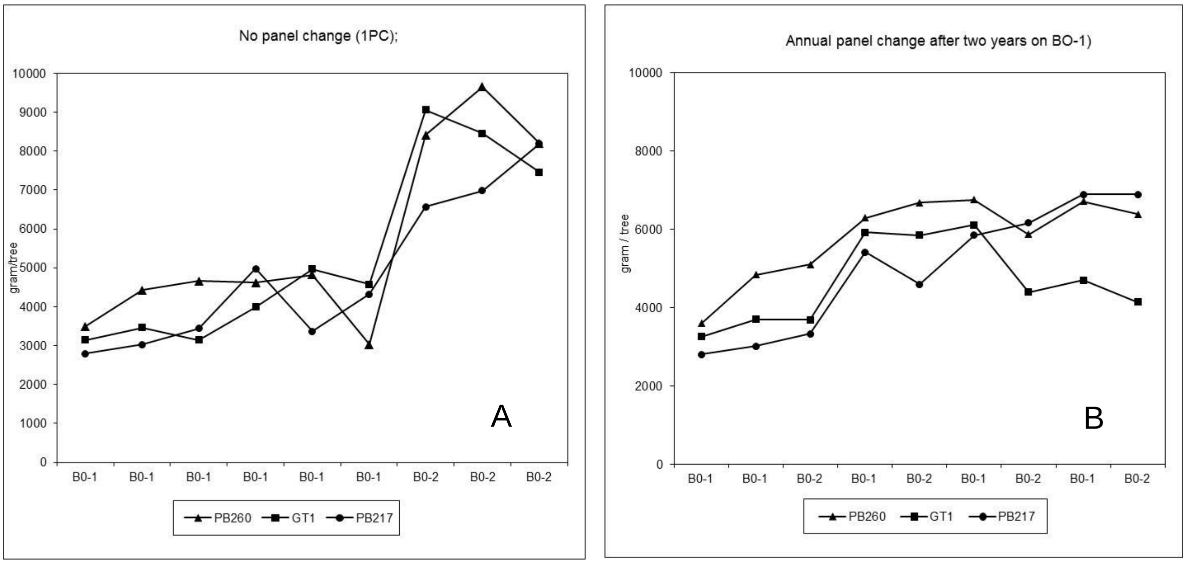


Fig 5: Annual yield (gram/tree) per treatment and per clone. A: No panel change (1PC); B: Annual panel change after two years on BO-1 (control).

Figure *6* shows the evolution of the annual sucrose (Suc), inorganic phosphorus (Pi) and thiols (R-SH) contents. Note the low content of Suc for PB260, the high content of Suc for PB217. The sucrose content of the latex was sensitive to panel changes Consecutive tapping years on Panel BO-1 were detrimental to the sucrose content for all clones. Each change over on Panel BO-2 was favorable to the sucrose content. As previously seen for annual yield, an opposite trend was observed between Treatment A and Treatment B, in year 7, 8, and 9. For all clones, the sucrose content of Treatment A was the highest at the opening of Panel BO-2 in year 7. PB260 showed the most little difference between the two panel management, having the lowest sucrose content along the tapping years.

With clones PB260 and GT1, treatment A had a lower Pi content in year 4, 5, and 6, followed by a sharp increase in the 7th year for clones PB260, PB217 and GT1 with the high level only for PB260, consecutive to the opening of Panel BO-2 (Figure 6). The trend from the 7th to 9th year was higher and slightly greater respectively for clones PB 60 and PB217 than GT1. For treatment B, the trend of Pi was more regular for all clones than for treatment A.

Thiols contents from Treatment A were much lower in the first 6 years on Panel BO-1 and higher in years 7 and 8 on the new Panel BO-2 for clones PB260 and GT1. The other panel management, B, showed similar thiols contents, decreasing from the 4th and 5th tapping year. Treatment B showed the lowest thiols content the last two years, 8 and 9, for clones GT1 and PB260.

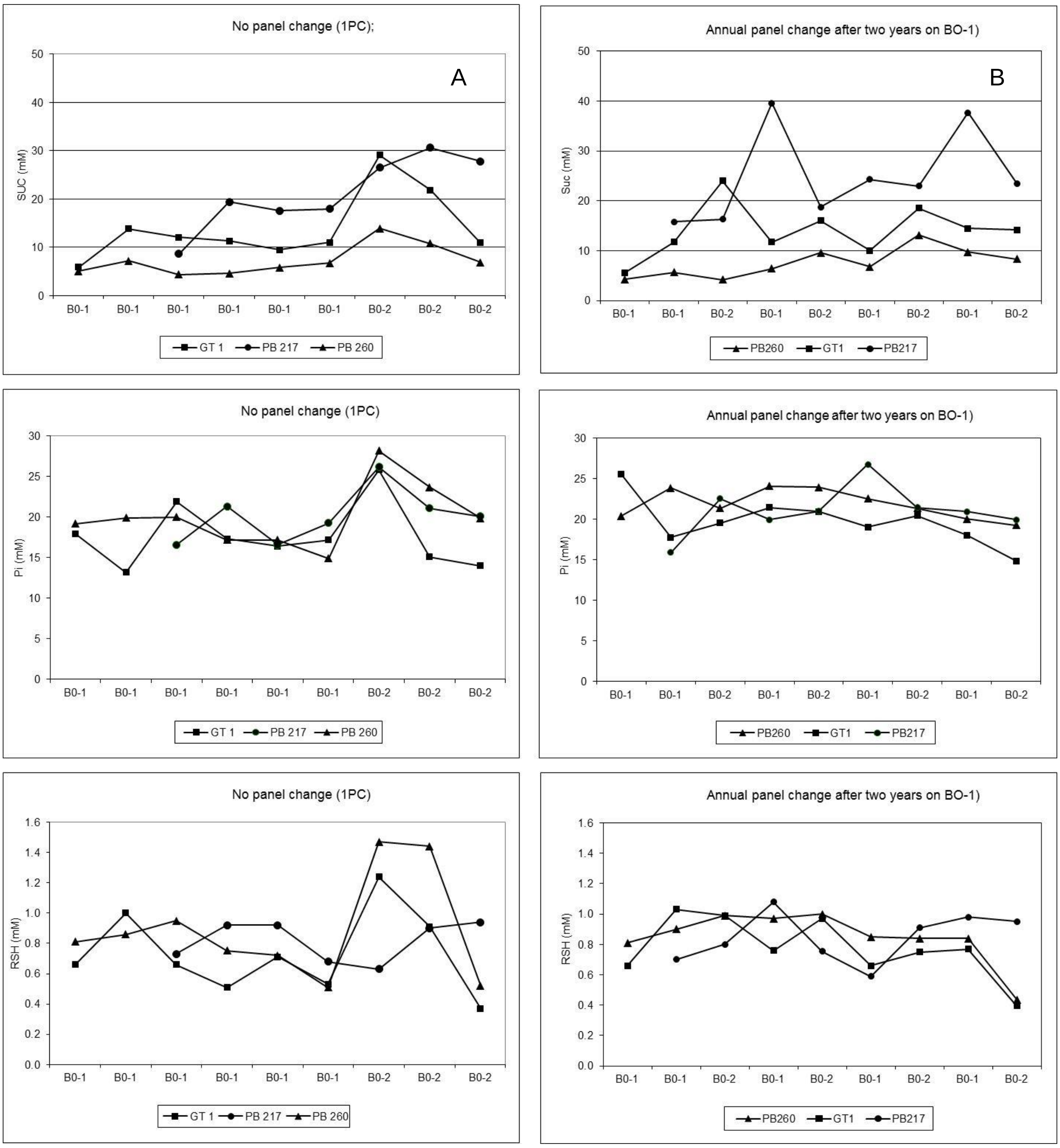


Fig 6: Evolution of the annual sucrose (Suc), inorganic phosphorus (Pi) and thiols (R-SH) contents per treatment and per clone. A: No panel change (1PC); B: Annual panel change after two years on BO-1 (control).

4. Discussion

The purpose of these studies was to characterize the long-term behaviour of the rubber tree under ethephon treatment and panel management strategies by comparing:

- the effect of ethephon stimulation in two high yield clones IRCA130 and IRCA230 with the GT1, and PB217 clones.
- the effect of the panel management on clones showing different physiological characteristics of latex: GT1, PB260 and PB217.

Long term effect of ethephon stimulation:

By the use of a gradient in stimulation frequency (first study), clones are well characterized by their metabolic activity as demonstrated in the clonal typology of latex functioning by Jacob *et al.* (1989). Without stimulation, clones IRCA130 and IRCA230 produced high latex yields (P0) with high latex inorganic phosphorus content (Pi_{P0}) and low or medium latex sucrose content (SUC_{P0}). GT1 and PB217 had low latex yields associated with low Pi_{P0} and medium or high SUC_{P0}. These preliminary results confirm previous results by Serres *et al.* (1988) and Eschbach and Lacote (1989) for clone characterization without stimulation.

There is no need to stimulate the metabolism of clone IRCA130 with ethephon, as the difference between maximum latex yield (Pmax) and latex yield without stimulation (P0), ΔP, was zero. The same was observed by Serres *et al.* (1988) in other clones with a high metabolic activity, like PB 235 and PB260. These high-yielding clones, (including IRCA130 in our study), have inorganic phosphorus content (Pi_{P0}). A high Pi_{P0}, prior to ethephon stimulation, indicates strong cellular activity able to produce high latex yield (Jacob *et al.,* 1989): the positive relationship between P0 and Pi_{P0} was noteworthy.

The sucrose content of non-stimulated trees was lower in clone IRCA130 than in IRCA230, GT1, and PB217. According to Lacote (1991), clones with a faster metabolism, like IRCA130 and even IRCA230, consume more sucrose to produce more than other clones. Hence, sucrose transportation within the latex cells has to be secured (Eschbach *et al.*, 1986). Subsequently the use of sucrose in latex metabolism has to be efficient. Our results, without stimulation, underlined the importance of the sucrose sink strength and the metabolic efficiency as a major clone characteristic, as previously suggested by Serres *et al.* (1988) and Gohet (1996).

The potential increase in yield ΔP varied with the clone. The highest ΔP was obtained in clone PB217 with the lowest P0 and the highest SUC_{P0}. The strong positive correlation between ΔP and the initial sucrose content of the latex cells (SUC_{P0}) revealed a strong relationship between SUC_{P0} and the ability of the trees to produce more under stimulation (Gohet, 1996). Our results showed that the sugar loading capacity of the latex cells (high SUC_{P0}), considered as the ability of the sink to import carbohydrates (Tupy and Primot, 1976; Eschbach *et al*. 1986, Ho 1988; Patrick 1997, Silpi *et a*l. 2006, Silpi *et al.* 2007, Chantuma *et al.* 2009), is one of the main factors that enables a significant increase in latex yield after ethephon stimulation (Gohet *et al.*, 2001 and 2003).

This also implied that increasing latex yield by increasing metabolic activity (high ΔPi) with ethephon stimulation is only possible when the latex cell metabolism is relatively less active (low Pi_{P0}). When the inorganic phosphorus content prior to ethephon stimulation (Pi_{P0}) is low, the sucrose content (SUC_{P0}) is high in the latex cells. In that case, ethephon stimulation increases rubber biosynthesis and latex yield more efficiently. In clones with a low metabolism like PB217, stimulation can strongly activate their metabolism as there is a large amount of sucrose available *in situ* and as the biochemical organisation controlling latex regeneration responds to ethephon stimulation (Chrestin *et al.* 1985). By contrast, high inorganic phosphorus content associated with low sugar content is a sign that the latex cell metabolism is already rapid. Active clones like IRCA130, do not need stimulation to produce an acceptable yield or ethephon stimulation must be used with care. Exceeding the limits of their biochemical characteristics will probably trigger latex cell dysfunctions, involving senescence events in the case of over-stimulation by ethephon (Chrestin, 1985, Chrestin *et al.,* 1985; Coupé and Chrestin, 1989, d'Auzac *et al.,* 1997).

Panel management strategy

A general trend emerges for clones PB260, GT1, and PB217.

For clones PB 260, GT 1 and PB 217 the cumulated yield after 6 years was higher for treatment B than for treatment A. At that period, treatment B underwent 4 panel changes, whereas treatment A had none. The gain was 8 kg per tree for clone PB260, and more than 5 kg per tree for GT 1. The performance of clone PB 217 was different, since, irrespective of the type of panel management used, yield continued to rise over time. The cumulated yield gain of clone PB 217 reached only 2.8 kg per tree over the first six years of tapping. After 9 years, the difference between treatments A and B was reduced to nil for clones PB 217 and PB 260, or even inverted in the case of GT1. This result can be explained by the high yield obtained by treatment A during the last tapping period (years 7 to 9) on the newly opened panel BO-2.

During the first 6 tapping years, in treatment A and for the clones PB260, GT1, and PB217, the low content of sucrose, inorganic phosphorus and thiols, could be considered as limiting factors of the latex cell functioning (Jacob *et al*. 1985, Jacob et al. 1989). The sucrose consumption (Jacob *et al*. 1985) the absence of carbohydrate reserves available for fuelling the laticifer metabolism (Gohet *et al.* 1998), and a low metabolic activity probably due to some physiological stress (Jacob *et al.* 1989, d'Auzac *et al*. 1997) have limited yield. These facts can explain the relatively low level of yield of treatment A for PB260, GT1, and PB217.

During the last tapping period (years 7, 8, and 9), in treatment A, a higher sucrose content was found in the newly opened panel BO-2. When associated with a high metabolic activity (Jacob *et al*. 1989, d'Auzac *et al.* 1997)) (indicated by Pi), it explains the yield relatively higher than that of the treatment B for PB260, GT1, and PB217 (Lacote *et al*. 2004). These results appear logical for the laticifer metabolism of PB260 which can be activated quickly on a new panel by tapping. This is logical for GT1 too. It is also observed for PB217 but to a lesser extent because the metabolic activation of this clone on a new panel is known not so fast (Serres *et al.* 1988, Jacob *et al*. 1989, Gohet *et al*. 1998).

5. Discussion - conclusion

Given that ethephon stimulation is an essential technique for increasing rubber yield; our results underline the importance of characterizing the latex cell metabolism of new clones since ethephon stimulation is not efficient in clones with rapid metabolism. These high-yielding clones require a smaller number of stimulations to produce more. In the long term, their potential yield will be lower than that of clones with lower metabolic activity. Among high-yielding clones, IRCA130 and IRCA230 are well characterized as quick starters that do not need too much ethephon stimulation. Their yield is high, but their latex cell metabolism is highly sensitive to ethephon, which could have negative effects in the long run. In high yield clones with low sugar content like IRCA130, no stimulation is necessary to improve yield. In clones like IRCA230, that have higher sugar content than IRCA130, eight ethephon stimulations per year was shown to be the optimum frequency to obtain the highest yield in Côte d'Ivoire. One way to increase potential yield by expanding the limits of ethephon stimulation is to select clones whose latex already has high sugar content. These clones, like PB217, namely slow starter clones, need more stimulation to produce more, but in the longer run there will be no negative effects of ethephon on the latex cells. These results will help planters optimize latex production by choosing the most appropriate ethephon stimulation to clones according to their latex cells biochemistry.

Regarding clones characteristics, the two panel management strategies which were compared in this study basically differ by the number of panel changes over a nine-year period of half-spiral downward tapping : 0 or 4 panel changes over the first 6 years, and 1 or 7 panel changes over 9 years for the four treatments respectively. For PB260, GT1, and PB217, the treatment with a maximum number of panel changes achieved a higher cumulated latex yield after six years than the treatment with a minimum number of panel changes. That advantage was reduced to nil after nine years or even inverted in the case of GT1. For that clone, the drawback was balanced by a yield, after nine years, higher than that of the treatment with the maximum number of panel changes, with a difference of 17 %; that could be explained by the high sensitivity of the trunk growth of GT1 to tapping and to latex export. Minimizing the frequency of panel changing, by tapping the panel BO-1 during six successive years and then tapping the panel BO-2 during three successive years, would generally not be obtained at the expense of a lower cumulated latex yield over 9 years. Moreover, it would be more simple and cost-effective. That panel management can be monitored with the assistance of latex diagnosis in order to detect important physiological stress which would indicate the need for earlier panel change (Lacote *et al.* 2004, Obouayeba *et al*. 2011)

Latex harvesting is a dynamic process completely determined by the evolution of the metabolic characteristics of latex (sugars and metabolism). It can now be modeled, allowing the prediction of the response to the new tapping systems considering:

- clones potential and response to stimulation (clonal typology),

- latex yield considering tapping panel position, tapping direction (downward tapping, upward tapping, combined upward/downward), tapping cut length (S/2, S/3, S/4 and S/8) and tapping frequency (d2, d3, d4, d5 or d6).

We were able to characterize the response of clones to latex harvesting practices: tapping and stimulation i.e. tapping panels' management. In this context, and from CIRAD database, the latex clonal typology, established by CIRAD, lays in a classification of *Hevea brasiliensis* clones in a 2 dimensions-matrix. The table 6 shows the "Latex Clonal Typology" matrix containing five different metabolic types (low, low-medium, medium, medium-high and high) and three different latex sugar loading types (low, medium and high). This typology allows to classify then to describe the response of any rubber tree clone to ethephon stimulation. For example, stimulation intensity is to be increased when clonal latex metabolic activity decreases and/or when clonal latex sugar loading capacity increases. Conversely, stimulation intensity is to be decreased when clonal latex metabolic activity increases and/or when clonal latex sugar loading capacity decreases (Lacote *et al.* 2004, Lacote *et al*. 2010). Latex Clonal Typology greatly simplifies stimulation recommendations, as only five different levels of stimulation intensity (very high, high, medium, low and very low) provide accurate stimulation recommendations to all physiological types of clones, depending on their position in the matrix (Jacob *et al*. 1995a, Gohet *et al*. 2005).

Table 6: CIRAD Clonal Latex Typology

Clonal Metabolic Typology. CIRAD
Physiological basis for tapping systems recommendations (tapping frequency, stimulation)

	Low Metabolism **Met-**	**Low-Medium Metabolism** **Met -=**	**Medium Metabolism** **Met =**	**Medium-High Metabolism** **Met =+**	**High Metabolism** **Met +**
Low Sugar Loading (Suc -)	***Typology c1*** ***Met - Suc -*** AVROS 2037 *High stimulation*	***Typology c3*** ***Met -= Suc -*** *Medium Stimulation*	***Typology c6*** ***Met = Suc -*** *Low Stimulation*	***Typology c9*** ***Met =+ Suc -*** *Very Low Stimulation*	***Low probability***
Medium Sugar Loading (Suc =)	***Typology c2*** ***Met - Suc =*** AF 261 *Very high Stimulation*	***Typology c4*** ***Met -= Suc =*** PB 86 PR 107	***Typology c7*** ***Met = Suc =*** GT1 PB 254 RRIC 100	***Typology c10*** ***Met =+ Suc =*** RRIM 600 PB 5/51 BPM 1 IRCA18 BPM 24 IRCA 109 RRIC 110 PB 330 PR 255	***Typology c12*** ***Met + Suc =*** PB 235 RRIM 911 PB 260 PR 261 PB 340 IRCA 111 RRIM 901 IRCA 130 PB 312 IRCA 209 PB 314 PM10
High Sugar Loading (Suc +)	***Low probability***	***Typology c5*** ***Met -= Suc +*** PB 217	***Typology c8*** ***Met = Suc +*** RRIC 121	***Typology c11*** ***Met =+ Suc +*** IRCA 19 IRCA 41 RRIM 921	***Typology c13*** ***Met + Suc +*** IRCA 230 RRIM 712 PB255

Diagonals of the [5,Met x 3,Suc] matrix : Homogenous stimulation recommendations

This physiological modelling thus allows predicting, in case of use of reduced tapping frequencies (d3, d4, d5 and d6), the recommended ethephon stimulation intensity that will be required for the clonal yield potential expression. In fact, these stimulation recommendations can be associated to 5 matrix diagonals, limiting to 5 the total number of possible stimulation recommendations for all clones.

This modelling is of great importance as it also induces significant reduction of time usually required to introduce newly selected clones into rubber farms. As a matter of fact, a few yield and physiological data obtained from these new clones, compared to those of control clones under same tapping conditions, are sufficient to precise their position in the typology matrix and therefore to perform early and accurate stimulation recommendations for these new clones. Long-lasting tapping system experiments usually set up to optimise stimulation recommendations are therefore less and less necessary.

Moreover, the panel changing concept can be reviewed, leading to simplified tapping panel management with optimized use of ethephon stimulation (frequency and intensity) in accordance with:

- the status of bark activation (or fatigue) on downward panel BO-1,
- the need to activate the latex generating metabolism of panel BO-2, *i.e.*, taking into account the agronomic and physiological characteristics of the clones,
- the need to harvest more long time the virgin bark by tapping the upward panels.

We consider the opportunity to having 3 successive tapping cycles in the life span of the rubber tree (Fig. 7)

- (i) conventional tapping on virgin bark (Fig. 7A):
    - phase 1, downward tapping during at least 10 years in S/2,
    - phase 2, upward tapping since the year 11 in S/4.
- (ii) conventional tapping on renewed bark, less used because tapping cycles are shorter, most of the time 25 years instead of 35 years before (Fig. 7B)
- (iii) intensive tapping before slaughtering (Fig. 7C)

Up to now, to get sustainable rubber production there is a need to improve the latex harvesting practices taking into account that at all times, the yield depends on:

- accurate choice of clones, by crossing c the choice on the following factors,
    - selection for high / activated latex metabolism
    - selection for high latex sugar reserves
    - selection for disease resistance (endemic leaf disease areas)
    - selection for wind damage resistance (high wind areas)
    - selection for climatic stress tolerance (climatic marginal areas)
- accurate planting material, planting design and maintenance
- optimized tapping systems
    - accurate opening policy (height, tapping angle)
    - accurate tapping frequency and stimulation rate (clone-based typology)
    - optimized panel management ("sugar supply management")
    - accurate opening policy (height, tapping angle)
    - accurate tapping frequency and stimulation rate (clone-based typology)
    - optimized panel management ("sugar supply management")
- optimal tapping quality
    - optimized bark consumption
    - optimized tapping deepness
    - limited (but not Zero) wounding
- optimized fertilization
    - optimization of sugar supply and loading to the latex (?)

At that moment, taking into account these factors, it will be possible to sustain rubber productivity. Regarding good latex harvesting practices, the possible recommended tapping system would ensure 22 years of tapping on virgin bark, integrating reversed quarter spiral tapping, in accordance with CIRAD recommendations.

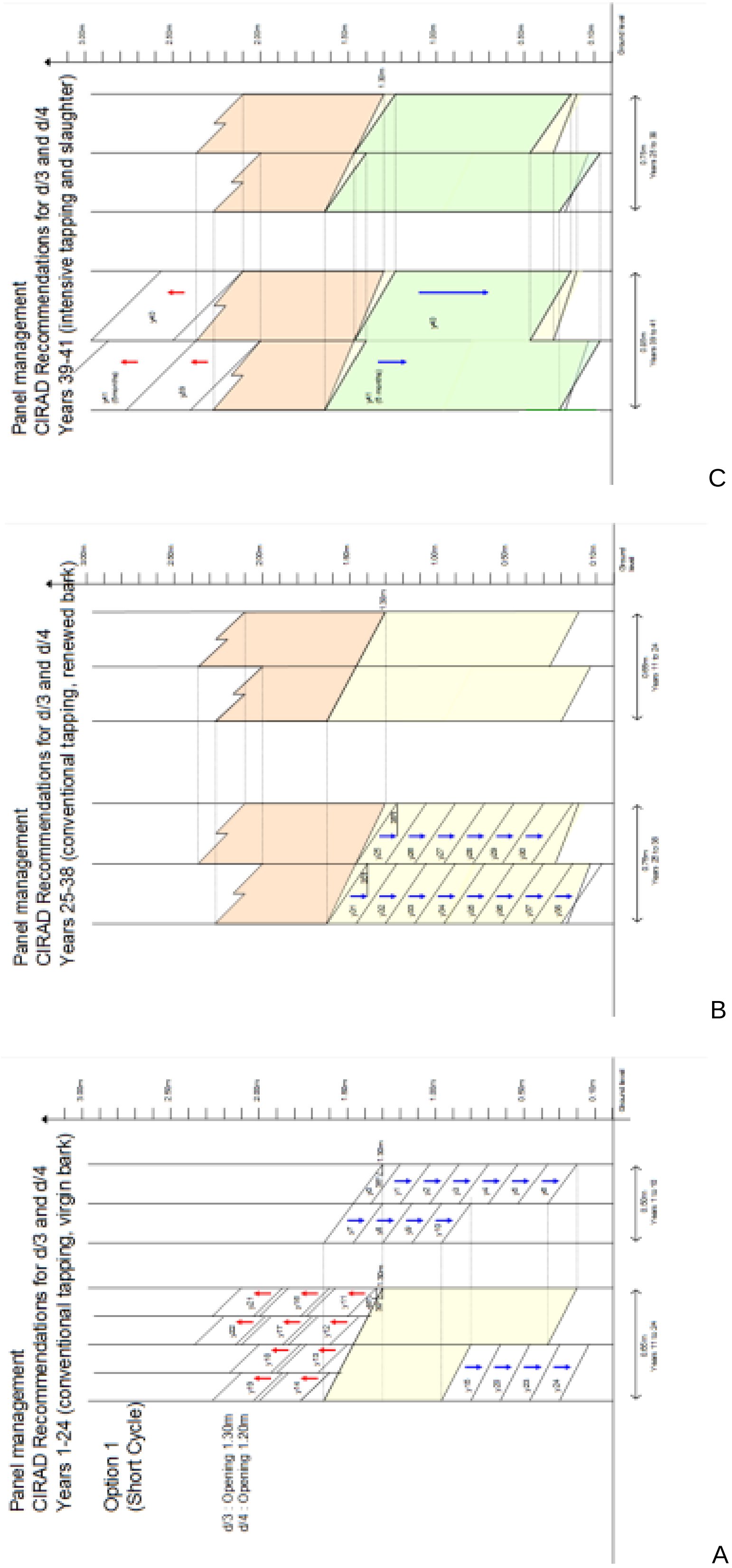


Fig 7: Tapping of the rubber tree, (A); downward tapping then upward tapping on virgin bark, (B); tapping on renewed bark, (C); intensive tapping both on renewed bark (downward) and on high virgin panel (upward).

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